The Shape of the Milky Way Halo and the Satellite Tidal Tails

M.A. Gómez-Flechoso

Universidad Europea de Madrid, Dpto. de Matemáticas, E-28670 Villaviciosa de Odón (Spain)

Abstract.
The dwarf galaxies orbiting a main galaxy suffer strong tidal forces produced by its dark halo. As a consequence, substructures and tidal tails could appear in the satellites. These structures could give us information about the dark matter content of the main and the dwarf galaxies. The Milky Way satellites, because of their proximity, are a good sample to study the effects of the tidal forces. The shape of the Milky Way potential could be inferred from the observational data of the tidal tails of its satellites. The Sagittarius dwarf is one of the most interesting satellites as it presents a long tidal tail that covers a wide angle on the sky with a large variation of heliocentric distance along the stream.

1. Introduction

Several processes are involved in the interaction between a galaxy and its dwarf satellites. The most important are the dynamical friction (producing the satellite orbital decay), the disk shocking (that heats the disc and disrupts the satellite), the variation of the primary galaxy potential by the mass accretion of the satellites, and the tidal stripping.

In this paper, we will study the tidal stripping. It gives place to the formation of two almost equal tidal tails, the leading and trailing tails, that roughly follow the satellite orbit. As the potential is the physical quantity that determines this orbit, if the shape of the tidal tails is observed, the main galaxy potential can be inferred.

The tidal streams of the satellite galaxies have been observed in some external galaxies as polar rings or traces of tidal tails. They have also been detected in some globular clusters and dwarf galaxies of the Milky Way (MW).

2. The tidal streams and the Milky Way system

Among the MW satellite galaxies having tidal tails, the most prominent is the Sagittarius (Sgr) dwarf spheroidal galaxy (Ibata et al. 1994). A great circle of almost 360 degrees has been recently identified as Sgr tidal stream (Majewski et al. 2003). Besides that, a great number of observations of the Sgr stream has been reported (Mateo et al. 1998; Majewski et al. 1999; Ivezić et al. 2000; Yanny et al. 2000; Ibata et al. 2001a; Martínez-Delgado et al. 2001; Dinescu et
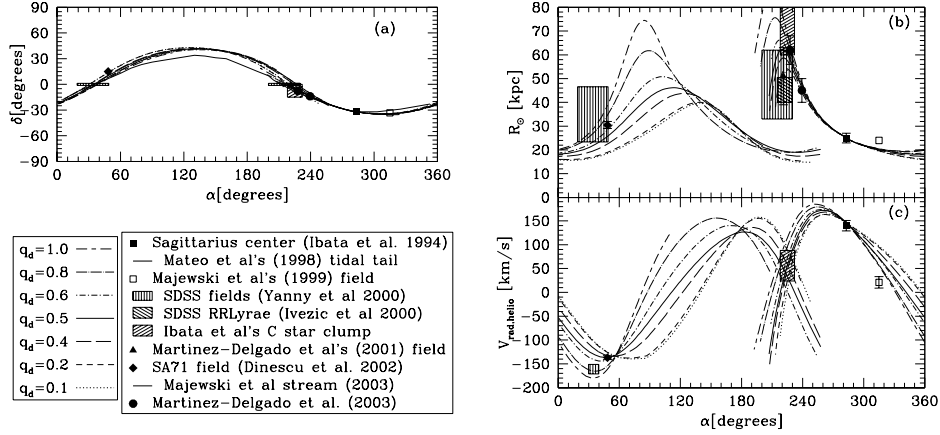
Figure 1.   (a) Projected position on the sky, (b) heliocentric distances and (c) radial velocities of the observational data and the analytical orbits of Sgr for several flatness of the MW halo density, q_d.

al. 2002; Martínez-Delgado et al. 2004). This set of observations provides data about the projected position, the heliocentric distance and the radial velocity of the stars in several parts of the stream. It gives us information about the shape and the kinematics of the Sgr orbit (see Sect. 2.2 and Fig. 1) and, therefore, about the shape of the MW potential. The importance of the Sgr stream is that it maps the whole orbit, covering a wide range of galactocentric distances and travelling through inner and outer regions of the MW potential.

2.1.   The Sagittarius + Milky Way model

We have used a three component model (Gómez-Flechoso et al. 1999) with several flatness parameters for the halo density, q_d, to describe the MW. In this potential, we have calculated the orbit of Sgr, forcing the model to reproduce the present position and velocity of Sgr.

2.2.   Results

We have compared the different Sgr orbits obtained for different halo density flatness with the observational data of the Sgr stream. Fig. 1a shows the projected position on the sky in equatorial coordinates of the observational data and the analytical orbits of Sgr. As can be seen, all the orbits have roughly the same projected coordinates. Therefore, it is almost impossible to infer the MW flatness using only the projection on the sky. However, the heliocentric distances and the radial velocities provide more information about the MW potential shape (see Fig. 1b and 1c). The heliocentric distances at the apocenter depends highly on the density flatness. The same behavior can be observed in the maximum radial velocity of the orbit. From this figure we can conclude that the halo density flatness is between 0.4 and 0.7.

3.   The potential of the Milky Way

The physical quantity that governs the satellite orbit is the MW potential, not the density distribution. Different density distributions can produce almost the same MW potential and, therefore, similar satellite orbits. However, different potentials will always produce different orbits. To analyse properly the results on the shape of the MW halo from other authors, we have to compare the MW potential flatness, not the density flatness.

Sgr spends most of its life in the outskirts of the halo (40-50 kpc). At that distances, the density flatness inferred from the is $q_d = 0.4 - 0.7$, and the potential flatness is $q_p = 0.8 - 0.9$ (see Martínez-Delgado et al 2004 for details).

These results are consistent with the MW potential flatness obtained by other authors (Olling & Merrifield 2000; Chen 2001; Ibata et al. 2001b), and they are also consistent with cosmological cold dark matter models that predict oblated dark matter halos (e.g. Dubinski 1994).

4.   Numerical simulations

We have also run numerical simulations of the Sgr satellite and the MW. Both galaxies have been modelled using N-body systems. The simulations have been restricted to the last few Gyrs. During this period the MW potential has remained almost constant. The earlier evolution of Sgr have been estimated using a quasi-equilibrium King-Michie model (see Gómez-Flechoso & Domínguez-Tenreiro 2001 for details).

The flatness of the MW density distribution in the numerical model is $q_d = 0.5$, that corresponds to the better Sgr orbit obtained in the previous section. The characteristics of the satellite and its orbit have been chosen forcing the model to fit the observational data of Sgr at the final snapshot. A detailed description of the models is given in Martínez-Delgado et al. 2004.

4.1.   Numerical results and discussion

The agreement between the numerical simulations and the observational data is very remarkable (see Fig. 2 for the agreement in positions). Only a little disagreement in positions between these results and the Majewski et al. stream exists in the less populated region of the stream. This region also corresponds to the oldest part of the stream (it has been unbound more than 4 Gyrs ago). One reason of the disagreement could be that the MW potential has evolved during the last 4 Gyrs and, therefore, the cosmological evolution of the MW should be considered in order to obtain realistic old tidal streams. Another reason could be the uncertainty on the observational proper motions of Sgr, since a small variation of the proper motions of the satellite center produces large differences in the positions of the stream at large distances of the Sgr main body. Obviously, another reason could be the necessity of improving the MW model.

5.   Conclusions

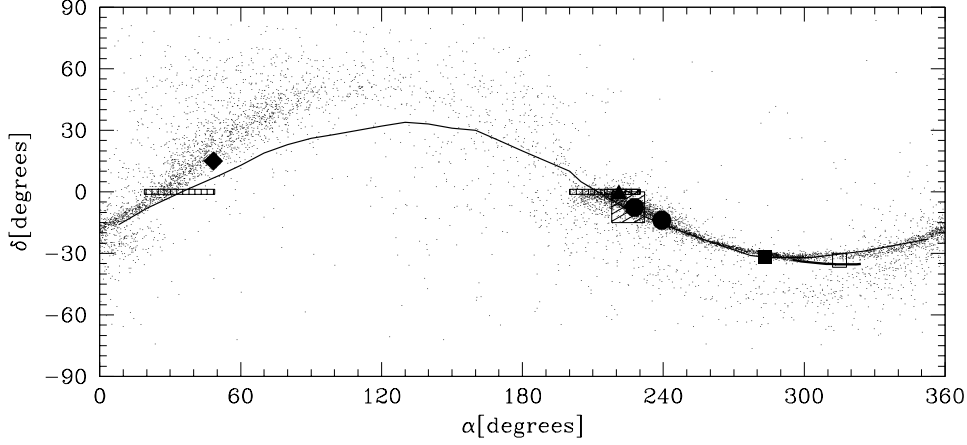1. The satellite orbits can be used to constrain the main galaxy potential.

Figure 2.   Projected position on the sky of the numerical model of
Sgr (black dots) and the observational data (the same as Fig. 1a).

2. Both distances and heliocentric velocities of the tidal stream are needed
to estimate the potential flatness. Using this method, we can only infer the
potential well of the main galaxy and not its mass distribution.

3. The results obtained from the Sgr stream are consistent with a MW halo
potential flatness $q_p = 0.8 - 0.9$ at the averaged radius of the Sgr orbit.

References

Chen, B., 2001 ApJ, 553, 184

Dinescu, D.I., et al. 2002, ApJ, 575, L67

Dubinski, J. 1994, ApJ, 431, 617

Gómez-Flechoso, M.A., Fux, R., & Martinet, L. 1999, A&A, 347, 77

Gómez-Flechoso, M.A. & Domínguez-Tenreiro, R. 2001, ApJ, 550, 703

Ibata, R., Gilmore, G., & Irwin, M.J. 1994, Nature, 370, 194

Ibata, R., Irwin, M., Lewis, G.F., & Stolte, A. 2001a, ApJ, 547, L133

Ibata, R., et al. 2001b, ApJ, 551, 294

Ivezić, Z., et al. 2000, AJ, 120, 963

Majewski, S.R., et al. 1999, AJ, 118, 1709

Majewski, S.R., Skrutskie, M.F., Weinberg, M.D., & Ostheimer, J.C. 2003, ApJ,
        599, 1082

Martínez-Delgado, D., Aparicio, A., Gómez-Flechoso, M.A., & Carrera, R. 2001,
        ApJ, 549, L199

Martínez-Delgado, D., Gómez-Flechoso, M.A., Aparicio, A., & Carrrera, R.
        2004, ApJ, 601, 242

Mateo, M., Olszewski, E.W., & Morrison, H.L. 1998, ApJ, 508, L55

Olling, R.P., & Merrifield, M.R. 2002, MNRAS, 311, 361

Yanny, B., et al. 2000, ApJ, 540, 825